EXPLOSIVE BONDING OF METALS

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Fig. 4

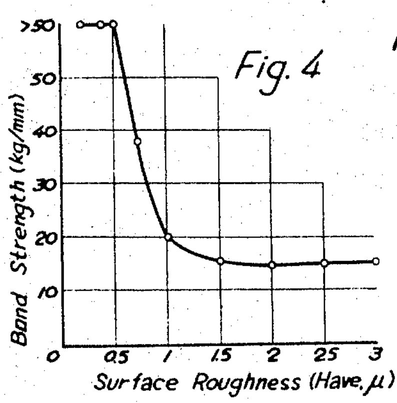


Fig. 1

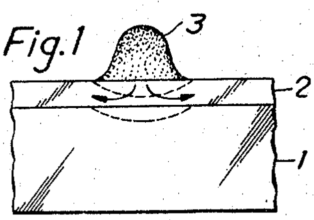


Fig. 2

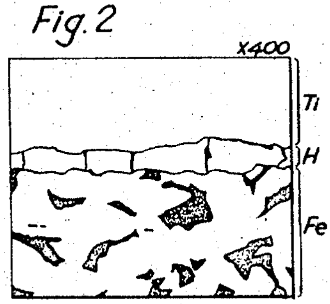
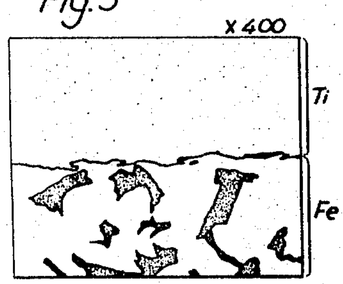


Fig. 3



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EXPLOSIVE BONDING OF METALS

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ABSTRACT OF THE DISCLOSURE

In explosive pressure bonding to steel of titanium, zirconium, tantalum, copper, aluminum, alloys based thereon, stainless steel, Hastelloy, Monel, nickel or ordinary steel, and more particularly in the explosive-pressure-bonding thereof in making clad steel plate, it is known that a hard brittle alloy layer is often formed at the region of the bond, which reduces the strength of the bond. Herein it is disclosed that the formation of such brittle layer is avoided by first finishing the surfaces to be bonded so that the roughness thereof, measured in terms of the centerline average height ($H_{av.}$) is less than 0.7 micron, then juxtaposing the so finished surfaces, and then subjecting the same to such explosive pressure bonding.

This invention relates to methods of explosive-pressure-bonding titanium, zirconium, tantalum, copper or aluminum or an alloy based on any of them with steel.

When these metals or alloys, referred to as titanium or the like hereinafter, are explosive-pressure-bonded with steel, a brittle hard layer will often be formed along the boundary of both metals. Such hard layer is believed to be composed mostly of an intermetallic compound of both metals. In the case of titanium, it usually shows a Vickers hardness of more than 800 and, as shown at H in FIG. 2, many micro-fissures are observed. If there is such a hard layer between the pressure bonded parts they will tend to exfoliate (i.e., peel or separate) and the exfoliation resistance will be reduced.

The extent and nature of such hard layer varies depending on the amount of the powder used in the explosive-pressure-bonding or, in other words, the magnitude of the explosive energy of the powder. If a powder of a large explosive energy is used, the formation of the hard layer will be great but, if a powder of a small energy is used, the formation of the hard layer will be small. Therefore, in order to make the formation of such hard layer as small as possible, a powder of a small explosive energy may be used but, in such case, the bonding force of the pressure-bonded parts will be reduced and no high exfoliation resistance will be obtained. It is not easy with the usual pressure-bonding techniques to reduce the formation of hard layer and increase the bonding force of the pressure-bonded parts.

The present invention is a method characterized by finishing the surfaces of two metal pieces to be pressure-bonded so as to be such smooth surfaces that the roughness of the surfaces will be less than about 0.7 micron and then explosive-pressure-bonding both metal pieces by using a considerable amount of a powder, thereby preventing the formation of a brittle hard layer in the pressure-bonded parts and increasing the bonding force of the pressure-bonded parts.

The principle of the explosive-pressure bonding is not entirely clear but is deemed to be based on the fact that a high heat by friction is generated in the bonded parts of both metals by impact waves due to explosion and, as a result, the atoms of both metals will diffuse with each

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other. Depending on the degree of diffusion of the atoms of both metals, such hard layer as described above will be formed between the metals. It can be presumed that, if the amount of generation of the above mentioned friction heat is adjusted to such degree that no hard layer may be formed, the formation of the hard layer will be able to be inhibited or prevented. It has been found that, in order to adjust the friction heat between both metals generated by explosion, it is advisable to control the roughness of the surfaces of the metal pieces to be pressure-bonded.

In the field of explosive-pressure-bonding, it has been considered that the surfaces of both metal pieces to be pressure-bonded had better be roughened with a grindstone. But if such method is applied to the specific field of explosive-pressure-bonding of titanium or the like with steel, a detrimental hard layer is formed as described above, and satisfactory pressure-bonding is not obtained.

In contrast to the conventional concept, the method of the present invention is directed to reduce the friction heat generated between both metals in explosive-pressure-bonding titanium or the like with steel. Thus, according to this invention, the metal surfaces to be pressure-bonded are worked or finished so that the roughness of the surfaces is reduced to a value of less than 0.7 micron, said roughness being a center line average roughness ($H_{av.}$). This unit of measurement of surface roughness is that used in England and Japan and means the center line average height (CLA) in microns (μ). The (CLA) measure in microns is related to the root mean square (RMS) measure used in the United States expressed in microns) by the formula: RMS $(\omega)=\text{CLA}(\mu)\times 1.1$. Thus CLA 0.7$\mu$ correspond to RMS 0.77μ and the horizontal ordinates in FIG. 4 if converted to the RMS measure expressed in micro inches) would be related to the illustrated scale as follows:

$H_{av.}$ (microns)	0.5	1	1.5	2	. . .
RMS (micro inches)	21.7	43.3	65.0	86.6	. . .

The invention will be explained in more details by referring to the accompanying drawings wherein:

FIG. 1 is a schematic view illustrating the explosive-pressure-bonding method;

FIG. 2 is a cross sectional view (magnification: 40 times) of a bond between titanium and steel obtained by conventional explosive pressure bonding method;

FIG. 3 is a view similar to FIG. 2 but showing the bond obtained by the present invention; and

FIG. 4 is a graph showing the relation between surface roughness and exfoliation strength.

As shown in FIG. 1, in case of explosive-pressure bonding a layer or lamina **2** of titanium or the like to a steel plate (base material) **1**, the base material and lamina material in the parts to be bonded will be plastically deformed in the directions indicated by the arrows due to the explosive impact waves produced by a powder **3** and, as a result, a high friction heat will be generated in the surfaces to be bonded. In such case, if the surface of the metal plates are rough, due to the quickly generated friction heat, the convex parts of the surfaces to be bonded will be locally heated to a high temperature and the mutual diffusion of the atoms of both metals will be accelerated so as to form a hard layer as shown in FIG. 2. But, as disclosed by the present invention, if the roughness of the surfaces to be bonded is very fine, the local heating to a high temperature will be very little, and the degree of the mutual diffusion of the atoms of both metals will reduce and, as a result, the formation of a hard layer will be inhibited. It has been found that in the case of explosive-pressure-bonding titanium or the like with steel, if the center line average roughness ($H_{av.}$) of the surfaces to be bonded of both metals is finer or smaller than about 0.7 micron, the formation of a hard layer will be substantially nil and a pressure-bond having a high exfoliation strength is obtained. (See FIG. 3).

The present invention can be applied for the same purpose in the case of explosive-pressure-bonding such acid-proof alloys as stainless steel, Hastelloy or Monel, nickel or ordinary steel to steel. That is to say, when such metal is explosive-pressure-bonded to steel, without using the present invention, a fused layer will be produced at the juncture and will have so many defects that a high exfoliation strength will not be able to be obtained. But, if the method of the present invention is applied, for the same reasons as are described above, the formation of such fused layer will be prevented and a very high exfoliation strength will be obtained.

The invention will be further described by referring to the following examples.

EXAMPLES

In the examples of Table I, titanium was bonded to steel by the explosive-pressure-bonding method. A steel plate 12 mm. thick and two titanium plates respectively 1.5 and 3 mm. thick were prepared. The surface to be bonded of each plate was ground to be of each of two kinds of roughness respectively of 0.4 to 0.5 and 2.5 to 3 microns ($H_{av.}$) by using an emery paper or grindstone. Then they were linearly explosive-pressure-bonded together by using a powder. In such case, the steel plate and titanium plate were rectangular, were overlapped as crossed with each other and were linearly pressure-bonded in the crossed parts. The exfoliation test was made by pulling both metal plates in the directions reverse to each other. In such case, the titanium plate was deformed by the tension and exfoliated inward from the end of the pressure-bonded part. Therefore, the value obtained by dividing the maximum tensile strength with the length of the linear pressure bond, that is to say, the exfoliation strength instead of the tensile strength per unit length of 1 mm. was indicated to obtain the data in the following table. The cross-section of the pressure-bonded part of the plate whose bonded surface had a roughness of 0.4 to 0.5 micron ($H_{av.}$) was as in FIG. 3 wherein no intermediate hard layer was formed. The data for these examples is tabulated in Table I.

TABLE I

Thickness (in mm.)		Roughness ($H_{av.}$) of the surface of the plate (in micron)	Exfoliation strength (in kg./mm.)
Steel plate	Titanium plate		
12	1.5	2.5 to 3.0	14.3
12	1.5	0.4 to 0.5	*56.5
12	3	2.5 to 3.0	6.3
12	3	0.4 to 0.5	46.5

*There was a break from the titanium plate.

As is apparent from this Table I, when the center line average roughness of the surface to be bonded was 0.4 to 0.5 micron, the exfoliation strength of the pressure-bonded part showed a value much higher than when it was 2.2 to 3.0 microns, whether the thickness of the titanium plate was 1.5 or 3 mm.

FIG. 4 shows the variation of the exfoliation strength of the pressure-bonded part in case the roughness of the surface to be bonded was varied when a titanium plate was to be explosive-pressure-bonded to a steel plate. It is seen therefrom that the exfoliation strength sharply rises when the roughness of the surface to be bonded is about 0.7 to 0.6 micron ($H_{av.}$). Thus the effect of the present invention is clearly shown. Though, in the same graph, the curve begins to rise at about 1 micron, in fact, there is a fluctuation of the exfoliation strength and a sufficient exfoliation strength begins to be obtained at about 0.7 micron.

For the examples of Table II stainless steel (JIS–SUS 27) plates 1.5 and 2 mm. thick respectively were made to be of surface roughness ($H_{av.}$) of 0.4 to 0.5 and 1.2 to 1.5 microns and were explosive-pressure-bonded to respective steel plates 9 mm. thick by the same method as in the preceding example. The results in the following Table II were obtained.

TABLE II

Thickness (in mm.)		Roughness ($H_{av.}$) of the surface of the plate (in micron)	Exfoliation strength (in kg./mm.)
Steel plate	Stainless steel plate		
9	1.5	0.4 to 0.5	*103
9	1.5	1.2 to 1.5	19.2
9	2	0.4 to 0.5	85.9
9	2	1.2 to 1.5	22.5

*There was a break from the stainless steel plate.

Further, the present invention has the same effect in the case of explosive-pressure-bonding not only titanium and stainless steel but also zirconium, tantalum, copper, aluminum, Hastelloy, Monel, nickel and ordinary steel to steel. The shape of the pressure-bond may be a point, line or area (as in titanium or the like with a clad steel plate).

What we claim is:

1. A method of creating a bond between steel and a metal selected from the group consisting of titanium, zirconium, tantalum, copper, aluminum, an alloy of any of the foregoing, stainless steel, Hastelloy, monel, nickel, and ordinary steel, which method comprises
   - (a) finishing the surfaces to be bonded to have a center line average roughness of less than about 0.7 micron,
   - (b) juxtaposing the so finished surfaces, and
   - (c) subjecting the said juxtaposed surfaces to explosive-pressure-bonding.

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